Interactive Surfaces and Learning Analytics: Data, Orchestration Aspects, Pedagogical Uses and Challenges

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ABSTRACT
The proliferation of varied types of multi-user interactive surfaces (such as digital whiteboards, tabletops and tangible interfaces) is opening a new range of applications in face-to-face (f2f) contexts. They offer unique opportunities for Learning Analytics (LA) by facilitating multi-user sensemaking of automatically captured digital footprints of students' f2f interactions. This paper presents an analysis of current research exploring learning analytics associated with the use of surface devices. We use a framework to analyse our first-hand experiences, and the small number of related deployments according to four dimensions: the *orchestration* aspects involved; the *phases of the pedagogical practice* that are supported; the *target actors;* and the *levels of iteration* of the LA process. The contribution of the paper is two-fold: 1) a synthesis of conclusions that identify the degree of maturity, challenges and pedagogical opportunities of the existing applications of learning analytics and interactive surfaces; and 2) an analysis framework that can be used to characterise the design space of similar areas and LA applications.

CCS Concepts
• **Information systems → Information systems applications → Collaborative and social computing systems and tools • Human-centered computing → HCI → Interaction devices.**

Keywords
Design; groupware; visualisations; design; dashboard; studies in the wild, awareness; face-to-face

1. INTRODUCTION
While there has been a growing interest in the potential role of Learning Analytics (LA) in mobile learning and online activities, to a large extent, students' learning still happens in face-to-face (f2f) settings [1]. Blended learning and massive online courses have become popular targets for LA solutions [11], but they are primarily, or wholly, focused on the non-f2f, online part of students' engagement in learning activities. However, the development of effective f2f communication and collaboration skills remain key 21st century competencies for employability and lifelong learning [13]. Group tasks typically require negotiation, brainstorming, and argumentation, usually in the service of some form of artefact design. These can be powerful vehicles for authentic learning, and typically have a major f2f element [18]. It has been emphasised that LA research has a particular perspective of attempting to understand learning as a whole, *in their full complexity* [26], which also includes f2f students' activity.

Emerging technologies such as touch and tangible interaction, gesture recognition and object tracking, have the potential to help support f2f students' activity from a LA perspective. These technologies have been increasingly moving from research to commercial applications over the last two decades in the form of varied types of interactive surfaces [9]. In this paper, we focus on multi-user *interactive surfaces* which are devices that allow touch and/or tangible interaction by one or more users. These include interactive tabletops, interactive whiteboards (IWB), tangible interfaces and smaller-scale devices such as tablets, which can allow transitions between individual and group work.

The proliferation of surface devices is opening a broader range of possible applications to facilitate and enrich face-to-face activities in educational contexts [12]. Affordances of interactive surfaces commonly include the provision of a work space that offers multiple direct input points so users can manipulate digital content with fingers or through physical trackable objects, while they communicate via speech, facial expressions, and gestures [9]. Less explored affordances of these devices include the unique opportunity they offer to automatically capture students' digital footprints that can be analysed and used to make f2f interactions 'visible'. Their intrinsic multi-user capabilities can assist in enhancing collocated exploration, discussion and sensemaking of LA indicators. Furthermore, Oviatt's research [19] argues for the critical role of creative sketching in learning, placing renewed emphasis on digital pens and surfaces.

These underexplored opportunities motivate the need to define key dimensions of a new design space, where surface technology and LA tools can meet to address f2f learning challenges. Such an explicit design space may not only be helpful as an instrument for describing and coordinating current research in the area (e.g. by identifying potential uses of the technology and challenges; and avoiding duplicate work), but may also provide a conceptual basis for the development of new LA tools targeting unmet needs.

Designing and deploying LA tools using surface devices require a comprehensive understanding of interaction design and the possibilities that these technologies offer, not just for learning and teaching, but also for learning analytics. The design space should also consider the pedagogical underpinning, the possible target actors, the teaching strategies, data sources, and the degree of maturity of development in this area. This paper presents a synthesis of conclusions drawn from an empirical analysis of the

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current research and authentic deployments of LA tools utilising interactive surfaces. To describe the design space in this emerging area, we use an analytical framework, drawing on principles from four sources: *i)* a framework of classroom orchestration [20]; *ii)* a framework to support the implementation of teaching practices [10]; *iii)* the *actors* who are commonly targeted by LA tools [25] and *iv)* the *iterative process* they commonly followed by these to use and respond to LA tools [27]. We analyse the technological and educational aspects of our first-hand experiences, and the small number of authentic deployments, of learning analytics utilising different types of interactive surfaces. In parallel, our approach allows us to analyse the maturity of the multi-user interactive surface technology and LA solutions by drawing a contrast between interesting pieces of research conducted in controlled lab conditions and authentic classroom deployments.

The contribution of the paper is two-fold: 1) a series of conclusions that identify the degree of maturity, orchestration aspects, challenges and pedagogical approaches of the existing applications of learning analytics in interactive surface-based settings; and 2) a combined framework that can be used to characterise the learning analytics design space and maturity in other areas of application. Moreover, the framework connects pedagogical principles with the practical metaphor of classroom orchestration in the context of the deployment of LA tools.

The rest of the paper is structured as follows. The next section provides an overview about touch and tangible interaction; and a definition of orchestration technology and its links with learning analytics. Then, we present the theoretical underpinning of our combined framework. After this, we describe the analysis of selected case studies using the framework, making an emphasis on the particular orchestration challenges, pedagogical uses and advantages of using interactive surfaces for LA purposes. We conclude with a discussion of the application of our framework, the maturity of the area and opportunities for future research.

2. RELATED WORK

2.1 Touch and Tangible Surfaces in Education

Surface computing is still a maturing technology, which has become a more *natural* alternative to traditional mouse and keyboard input by allowing users multi-touch interaction using fingers, hands or special pens [2]. This shift in input technology has opened the interaction space allowing a wide range of new collaborative and ubiquitous applications, especially for those tasks that are more effectively performed *face to face* [18]. Some example tasks that have been supported by interactive surfaces include group planning, diagramming, designing, data exploration, brainstorming, knowledge building, and information curation. However, whilst advancements in hardware have been rapid, application software for large surface devices is still in early stages compared with, for example, the market of mobile devices.

In terms of educational contexts, there has been a great interest in using large surface devices for supporting collaborative learning pedagogies. IWB's have been used to conduct whole class activities [9], both vertical and horizontal large touch screens have been used to conduct small group work [12], and multiple tablets have been interconnected to support tasks in pairs [28], or to show a user interface just for the teacher [12]. Moreover, the use of tangible objects on surface interfaces has been regarded by practitioners and researches as a particularly important feature for the cognitive development of young students' coordination and 3D orientation [6]. Tangible interfaces are promising for tasks that require the manipulation of objects, which is not possible in flat displays (examples have included narrative, biochemistry and simulation systems [6]). Increased interest has also been posed in the digital affordances of surface devices to support handwriting and sketching [19]. These are often more fluid ways for students to communicate and generate ideas, compared with the use of mice, and physical or on-screen keyboards.

Another use of large surface devices has been collaborative data visualisation, but not much has been done to support collaborative sensemaking of educational data. At the same time, there has not been much work in exploiting data captured by these devices in similar ways as it has been done with online systems. The capture and identification of f2f users' actions can impose particular challenges that are not present in non-f2f scenarios. For example, all online actions can be easily recorded and identified by asking the user for login credentials. Although overcoming data collection challenges can be a current challenge, there is an enormous potential to support f2f student's work in ways that have not been yet possible.

Overall, there has been a steadily increasing interest in using touch and tangible devices. Rather than having a wave of novel technology occupying the classroom, we are seeing a slower paced increase of surface technology used in several areas of life, including learning and teaching. It is timely to start considering the potential of the support that learning analytics can offer - in situ- and, conversely, the new areas of application that these emerging devices can bring to learning analytics.

2.2 Technology for Classroom Orchestration

The metaphor of *orchestration* takes account of the variability and complexity of classrooms and the key role of teachers in adapting the available pedagogic and technological resources to help students achieve their intended learning goals [7]. Orchestration technology may support the management of the orchestration or some part of it. This includes, for example, interfaces that help teachers manage the class workflow, enhance their awareness or track students' progress. The metaphor was further embraced by other researchers to explain several other aspects that need to be attended before and/or after the actual deployment of learning tasks, not only in the classroom, but also in online or blended learning scenarios [20]. This includes, for example, tools that support teachers to deploy their learning designs or reflection, assessment and re-design after the activity is completed.

In short, this perspective empowers teachers as drivers of classroom activities and advocates for the use of simple technologies that may have important effects. The effectiveness of orchestration and the extent to which teachers can respond to the ways students perform their tasks is critical because it directly impacts these students' activities, and therefore, their students' learning. Moreover, the metaphor has also been extended by the notion of distributed orchestration [24], considering that students and other actors of the learning process, can also be responsible for part of or all the orchestration tasks. Thus, this makes orchestration also applicable to self-managed learning scenarios.

Our work takes an approach based on orchestration as it is a dynamic perspective that attends authentic issues considering that learning activities that occur in the classroom may be affected by unanticipated processes and contingencies. Differently to learning theories that focus on cognitive aspects, orchestration is concerned with practical issues and tasks that are not directly linked with learning but can shape learning. This makes orchestration very relevant for deploying LA tools in authentic learning settings. Learning analytics can have a key role in supporting f2f and blended learning activities. To achieve this, a clear understanding of orchestration aspects is needed to create effective LA solutions in those f2f settings where teachers or students need to adapt to unexpected problems, on the fly.

3. THE COMBINED FRAMEWORK

The combined framework we used to analyse the current research and deployments that combine LA tools and interactive surfaces is defined by four dimensions: a) a set of *orchestration aspects* that the LA tools provide support to, b) the *phases of the pedagogical practice* that are supported, c) the *target actors* of the learning analytics and d) the *levels of iteration* of the learning analytics and pedagogical processes (see Figure 1). The combined framework forms a 4-dimensional matrix which can categorise the LA deployments. Each of these dimensions, and their theoretical underpinnings, are described in the rest of this section.

3.1 Elements of the framework

3.1.1 Orchestration aspects

Prieto et al. [20] developed a framework that identifies five orchestration aspects. For the first dimension of our analysis framework, we considered the first four 'functional' aspects of orchestration (see Figure 1, a). These aspects can be linked with tasks that either teachers or students should perform, and thus, LA solutions can be created to support the actors in performing such functions or tasks. The fifth aspect refers to the roles of teachers, students and other actors, and was considered into a separate dimension, linked to the target actors of the LA tools (Figure 1, c). The four functional orchestration aspects are the following:

Design and planning. Learning design includes the preparation of the educational materials, pedagogical approaches, social dynamics, tasks, scripts, strategies and any other resources that are needed to create opportunities of learning for students. Teachers commonly have a crucial role in learning design and co-design. There can also be other actors specialised in learning design, particularly in higher education. Alternatively, students can also design or co-design their own learning tasks. The design process is not necessarily linear, as design and planning can co-occur while the actual activity unfolds or after it is completed [20]. In terms of learning analytics, awareness and/or analytical tools may support fine tuning of learning designs by providing visualisations of student's data, indicators about how planned tasks actually occurred or insights from the community of practice.

Regulation and management. This aspect refers to the coordination of the ongoing teaching process and/or the self-regulation of the learning activity. This includes the management of time for each student's task, class duration, task distribution and social arrangements. In short, this aspect is focused on the coordination of the workflow of the learning activity. This regulation can be performed through social interaction (e.g. the teacher directing the flow of the class or students managing their own workflow based on feedback from LA systems) or be partly handed over to some Comp. controlled mechanism [20]. LA tools can support the actors responsible of the management of the learning processes and their constraints by providing, for example, key information about the execution of the workflow so they could modulate it according to the demands of the activity.

Adaptation, flexibility and intervention. This aspect refers to the capacity of the educational technology, the class script or the

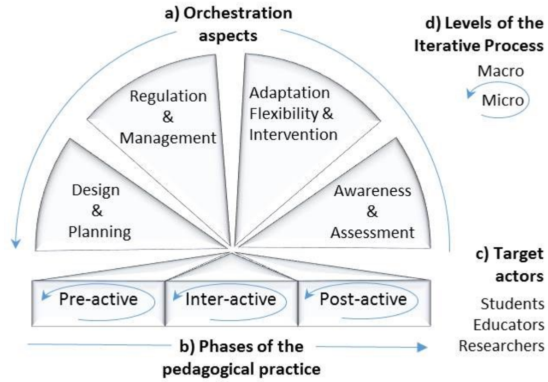

Figure 1. A combination of frameworks creates this 4-dimensional framework, used to analyse the current state of learning analytics on data from interactive surfaces

learning activities to be flexibly adapted to unexpected classroom events and the emergence of new tasks. This can include the actors creating improvised tasks or adapting the planned tasks during the enactment. Similarly, the systems can offer flexible functions to handle those adaptations. LA tools can support this process by providing teachers or students with key information that would allow them to manually intervene or adapt specific learning tasks, or for the learning system to automatically adapt the tasks to particular student's needs or provide automated interventions to tune the order or the approach to the tasks.

Awareness and assessment. Awareness, and formative/summative assessment tools are clearly critical to orchestrating learning. While 'awareness' of different sorts pervades all sensemaking activity around data [27], for this aspect we focus on those awareness mechanisms that are particularly linked to the students' learning activity. This includes tools that can provide key insights into students' learning processes so actors can modify their teaching strategies, the provision of feedback, the pedagogical approach or the students learning styles. These can be simple tools such as basic visualisations of group progress, or more complex student modelling or predictive approaches.

3.1.2 Phases of pedagogical practice

The second dimension is derived from the Implementing Collaborative Learning in the Classroom (ICLC) framework by Kaendler et al. [10]. This points at the teacher competencies that are needed across the implementation phases of learning strategies in classroom sessions. It defines five teacher competencies: *planning, monitoring, supporting, consolidating and reflecting*, which span three phases of teaching practice: *pre-active, inter-active, and post-active* (Figure 1, b). The authors map planning to the pre-active-phase, monitoring, supporting and consolidating to the inter-active phase, and reflecting to the post-active-phase. Although the teacher competencies could be matched with the orchestration aspects described above, the metaphor of orchestration is not only concerned with the ability of the teacher to perform tasks according to their professional knowledge. Rather, it is concerned with how different types of technology can support teachers, or students themselves, to manage multi-layered activities in a multi-constraints context [7]. Additionally and very important is that almost all orchestration aspects can be relevant before, during or after the activity [20]. For example, planning and learning design commonly occur in the pre-active phase, but it can be that a teacher has to adapt the intended design on the fly, or accomplish some re-designing work in the post-active phase.

In summary, by combining both frameworks we can map surface-based LA in terms of *what* orchestration support they provide and *when*. We have not yet specified *for whom*, considered next.

3.1.3 Target Actors

LA solutions can be oriented towards different actors of the learning process, including students, teachers, intelligent agents, administrators, etc [5]. At the same time, LA studies can be conducted for research, or prototype system design purposes, without being deployed in authentic learning scenarios. Learning analytics can also support learning designers to take informed decisions about changes that the course may require based on evidence. Therefore, to understand the design space of learning analytics in a specific area, and its degree of maturity in terms of real deployments, we should differentiate the actors who are being targeted as end-users of the LA tools. Based on the users targeted by the current deployments covered in our analysis, we divide the target users into three groups (Figure 1, c): *Students, Educators* (including lecturers, tutors, learning designers) and *Researchers* (including individuals and also the community of research).

3.1.4 Levels of the Iterative Process

The fourth dimension introduces the notion of iteration, at two levels: *Micro and Macro* (Figure 1, d). Micro refers to the iterative process of LA support within each pedagogical phase. This has been described by Verbert et al.'s [27] as the process users follow to: have access to data (*i. awareness*); ask questions and assess the relevance of the data (*ii. reflection*); answer questions, getting new insights (*iii. sensemaking*); to finally induce new meaning or behavioural change (*iv. impact*). This four-stage iterative process occurs while users interact with a LA tool in a given phase. Iteration at a *macro-level* is concerned with the workflow as the phases (*pre-active, inter-active,* and *post-active*) are repeated over multiple sessions. This is crucial so that LA tools can provide support spanning multiple sessions.

In summary, the combined framework considers that the pre-active, inter-active, and post-active phases form a linear workflow for one specific session (e.g. a classroom session, an experimental trial, an online-based task). Each orchestration aspect can be supported in any of these phases (e.g. planning is not restricted to the pre-active phase, but can occur in the inter-active and post-active phases). Finally, LA support can be targeted at different actors in each phase and macro-iteration.

4. Analysis of Case Studies

In this section, we analyse a series of case studies of LA applications that use interactive surfaces to support different orchestration aspects. Table 1 presents an overview of the design space defined by the dimensions of our framework. The table maps the *Projects* analysed (column 1), the *Orchestration Aspects* addressed (2-5); the *Pedagogical Phases* that are supported (6-8); and whether they involve certain levels of *Iteration* (9-10). The actors targeted in each deployment are represented by letters: E for educators, teachers, tutors and learning designers; S for students and R for researchers. Beyond the dimensions of the combined framework, in the case studies we seek to identify the *forms* in which the data is communicated to the actors, such as whether it is presented in a raw format (e.g. statistics, algorithms results, patterns), through visual representations (e.g., dashboards, visualisations, alerts, notifications) or by direct automated actions. We also pay attention to the topology of LA tools classified by the *type of information* they offer, including information about 1) the task/class progress, 2) students' interaction, 3) quality of the students' solution and 4) learning (including conceptual change, learning to collaborate or learning about the process).

In the following subsections, we provide a concise description of our first-hand experiences from seven case studies (the first 7 rows in Table 1). These illustrate how the dimensions of the combined framework are interwoven to help understand the technologies used and pedagogical aspects tackled by the LA solutions. To facilitate the presentation of the cases, we grouped them by the main actors that are targeted in each (teachers, learning designers, students and researchers, respectively). Lastly, we briefly describe other LA applications where some sort of surface technology has been used (last four rows of Table 1).

4.1 Supporting Awareness for Teachers

We start by describing two case studies of analytics support for enhancing teachers' awareness.

4.1.1 MTFeedback: driving teacher's attention

The first case study consisted in providing support to enhance teacher's classroom *Awareness and Assessment* on the fly (inter-active phase). The pedagogical intentions of the teachers were that students could engage in collaborative discussions and visually represent their proposed solutions to posed challenging problems. The teacher aimed to conduct this activity face-to-face to support students and provide direct feedback to promote verbal discussion and argumentation. The setting used was the MTClassroom (Figure 2, left). This is a multi-surface classroom environment composed of 4-5 large interconnected tabletops and three vertical displays. Each tabletop was enriched with a Kinect sensor that differentiates individual touches. This allows the capture of an identified log of student's actions at each table. A total of 6

Table 1. Analysis of the current design space of learning analytics applications utilising interactive surfaces. Target actors: E=Educators, S=Students, and R=Researchers

Project	Orchestration Aspects				Pedagogical Phases			Iteration	
	Design & Planning	Regulation & Management	Adaptation, Flexibility, & Intervention	Awareness & Assessment	Pre-active	Inter-active	Post-active	Micro-level	Macro-level
MTFeedback [15]				E		*		*	
Analytics for redesign [17]	E	E		E	*		*		*
CoCo Design table [16]	E, R				*			*	
Navi Surface [4]				E,S		*	*	*	
LARAe.TT [3]		E,S		E,S		*	*	*	
Co-located eye-tracking [23]				R		*			
Motion sensors [22]				R		*			
Script awareness tool [14]		E	E			*		*	
Do Lenh [8]				E, S		*		*	
Monitoring tablets [28]				E		*		*	
Learning catalytics [21]				E		*		*	

Figure 2. Left: An ongoing small-group session in the MTClassroom. The teacher is holding a tablet-dashboard while providing feedback to one team. Right: The dashboard showing visualisations of participation for 4 groups

teachers and more than 300 students were involved in a series of realistic studies conducted during three regular semester courses. Three types of tasks were facilitated by the tabletops: collaborative concept mapping, brainstorming and scripted group meetings. All the tabletops and the vertical displays were controlled by a teacher's tablet-based dashboard (Figure 2, right). This also showed visualisations that conveyed student's information in two dimensions: individual participation and group progress in their task. It also showed notifications from the MTFeedback subsystem. This analysed student's artefacts in the backend to generate both positive and negative notifications according to the groups' misconceptions or underperformance, automatically identified based on thresholds set by the teacher.

Empirical evaluations studied if the visualisations and notifications shown in the dashboard effectively supported teachers' *micro-level iterative LA process*, by *enhancing their classroom awareness* and thus allowing them to take more informed decisions when selecting the groups that required more attention [15]. Results indicated that the system helped to seamlessly capture traces of students' activity, thus allowing the generation of live visualisations and notifications for the teacher. The deployment of the teacher's dashboard on a tablet allowed free mobility to the teacher while having access to control and monitoring tools. The visualisations and the notifications allowed teachers to attend to groups that needed immediate support and provide formative and/or corrective feedback, which translated into student's conceptual changes.

4.1.2 Learning Analytics for Redesign

The second study consisted in providing LA support in two forms [17]. First, in the post-active phase, enhancing teacher's *Awareness* and helping her *Assess* how the initial intentions played in the classroom. Second, in the pre-active phase of the next class session, providing insights into the aspects of the learning tasks that need to be *Redesigned*. The setting was the MTClassroom as for the first case. This study focused on one teacher designing and then re-designing 1-hour tutorials for two different subjects in two consecutive university semesters. The first tutorial involved 236 students distributed in 14 classroom sessions. The second involved 140 students distributed in 8 sessions. The goals and the topic of both tutorials were similar: to promote discussion, and deep understanding of political dynamics for students to learn how to address organisational issues. Both tutorials had a similar macroscript which basically consisted of two small-group concept mapping tasks. The captured data included: application logs, snapshots of the evolution of each group's concept map and how the teacher advanced the class according to her script. Three semi-structured interviews were held with the teacher after the tutorials to capture teacher's intentions and reflections. Teacher's intentions were grouped into three categories: class script progress (A), student's participation (B), and students' achievement (C) in all sessions. In the first the LA support was presented to the teacher in the form of visualisations (graphs), workflow diagrams, and raw numerical results about each of the three pedagogical intention categories. This supported teacher's reflection in the post-active phase of the first macro-level iteration of the learning analytics cycle [17]. The next two interviews focused on capturing the teacher's re-design decisions as part of the pre-active phase of the next iteration. For example, regarding the class script (A), the teacher was provided with a fuzzy workflow diagram (e.g. see Figure 3). She identified that in most tutorials, students spent too much time in the first task, not giving enough time for completing the second task. Concerning student's participation (B), a bar chart was shown to the teacher, indicating that within most groups participation had not always been equally distributed. A third example (for category C) is illustrated by the results from a correlation analysis which suggested that a hierarchical concentric arrangement of students' concept maps was connected with the achievement of better solutions. These insights were informative for the teacher to re-design the tutorials. For the next tutorial sessions, the teacher provided an initial scaffolding solution for students to progress more quickly and focus on the subsequent higher-level tasks. The teacher also developed a strategy to encourage all students to use the tabletop, and to follow a specific concentric layout.

In this study, the surface devices allowed the automated collection of classroom evidence. The data was exploited to generate visual and non-visual information to help a teacher compare her planned intended goals with how they actually played in the classroom. This example illustrates the synergy between surface technology and learning analytics to provide continued macro-iterative support to teachers' awareness and planning, across sessions.

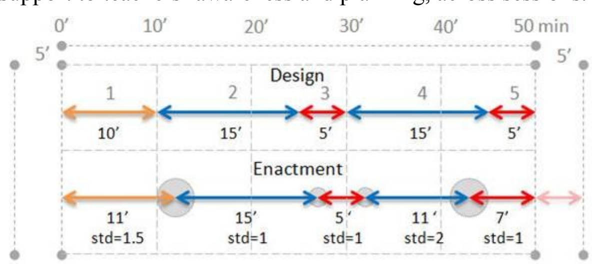

Figure 3. Planned time limits for 5 tasks (top row) and the enactment of the design for 14 tutorials (bottom row) [17]

4.2 Analytics for Learning Designers

One of the functionalities of using large interactive surfaces is that they invite all team members to interact with the shared device, making their actions visible. The next subsection describes a case study of analytics support for learning design.

4.2.1 CoCoDT: collaborative educational design

This case study consisted in supporting *Design and Planning* in the *pre-active* phase. The goal was to understand how surface technology and minimalist visual analytics can support high level *learning design*. The setting was the Design Studio [16]. Figure 5 shows this multi-surface space providing a set of digital and non-digital tools, including: a tabletop, an IWB, tablets, a white-wall, a dashboard, and various paper-based materials. The tabletop and

Figure 5. Left: A group of deigners looking at the dashboard while designing 2 candidate designs (A and B) in the Design Studio. Right: The dashboard showing: a) the tasks included in each design, b) the proportion of tasks by learning space, and c) the weekly distribution of student's time between online and f2f work

the IWB run an application called CoCoDT. It offers a large interface customised to support rapid construction of candidate designs as part of the early stage conceptual design of university courses. The tool shows a flipped timeline where users can arrange learning tasks on a weekly basis. This allows the manipulation of iconic digital objects to configure spatiotemporal characteristics of learning tasks and their workflow.

The dashboard shows live visualisations of the candidate designs created in the surface devices. This information includes a list of the learning tasks added to each candidate design, a pie chart that shows how students' time would be divided among learning spaces (face-to-face and online), and a histogram showing the student's weekly workload (see Figure 5, right). The goal of presenting a dashboard with visualisations of multiple candidate designs is to support teachers' high level comparison and promote understanding of the impact of substituting certain learning tasks for *equivalent* tasks on students' workload and direct contact time.

Four teams of three teachers and learning designers participated in an observational lab study. The goal of each team was to produce two candidate high-level designs of a university course, satisficing some competing design goals. Results of the study showed that the dashboard was one of the features that was most valued by participants. It provided an overall view of the tasks within each design and helped most groups in keeping themselves on track toward their design goals by having continuous access to indicators of their designs. Moreover, the participants valued the combination of large devices to have a view of the designs, smaller sized tablet devices to seek information as needed, and the dashboard to keep awareness of the changes on their designs.

4.3 Collaborative LA Data Exploration

Collaborative tools have been used to help small groups keep a shared view and articulate their insights more fluidly than with single-user displays. Surface devices can be used to support collaborative reflection on educational data. Next, we describe two case studies of collaborative LA exploration.

4.3.1 Navi Surface

This case study aimed to support students by enhancing their *Awareness* about their achievements to help them self-*Regulate* their own learning. The approach relies on a students' dashboard that can be used in the inter-active and/or the post-active phases (see Figure 4). The third author and his colleagues used the notion of badges to create Navi Surface [4]. Badges are used to abstract important aspects of student's learning processes, including intended learning outcomes and produced artefacts such as blog posts, shared documents. Navi Surface is a tabletop-based tool that allows teachers and students to navigate student's' achievements for a university course. Users can navigate through the tool to get more information about how and why badges were awarded to which students, based on the learning traces that were captured during the course. Multiple items can be accessed simultaneously, enabling group interaction with the data. The teacher can guide the process by dragging items onto the interface to promote discussion about what students have achieved, while students can also interact and steer the conversation.

Navi Surface was evaluated with 14 students (4 groups of 2, 3 and 4 members) who used the tool in groups and individually, and were able to access their personal data and that of others. Preliminary observations showed that the interface promotes engagement, group interaction and evaluation of achievements. This can be explained as follows. Most dashboards provide a single-user experience, requiring motivation (either intrinsic or extrinsic) from a student to access the LA data. The public nature of a tabletop (as opposed to a more private personal screen) creates a more inviting environment, facilitating a multi-user experience for students and their teachers to collaboratively explore LA data. The tabletop played a key role as catalyst of discussion and participants considered the approach as a fun way to interact with LA data. By contrast, when students used the tabletop alone, a more hesitant interaction was observed. These observations suggest that the collaborative nature of the surface device promoted social discourse which may

4.3.2 LARAe.TT

The second case study of this section includes the use of LARAe.TT [3]. Similarly to Navi Surface, this tabletop tool aims to support students' *Awareness* and *Reflection* in the inter-active and post-active phase, particularly for Inquiry-Based Learning (IBL) activities. In IBL, teachers encourage learners to pose questions and formulate hypotheses about a given topic, and accomplish independent investigations to support their conclusions. LARAe.TT visualises the paths that students follow through their inquiry-based learning activities. The tool is grounded on IBL process model which distinguishes the next six phases: problem identification, operationalisation, data collection, data analysis, interpretation and communication. Thus, students assume an active role to regulate their own learning as each learner can follow her own path. LARAe.TT allows students and their teacher(s) to discuss and retrace individual steps taken by students. They can look up related content such as hypotheses that were formulated, evidence data that was gathered, etc. Figure 7 shows the LARAe.TT interface, with the visual representations of

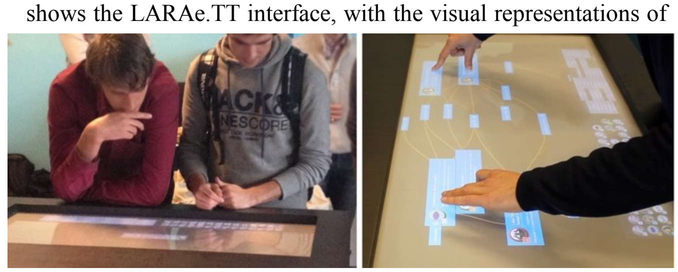

Figure 4. Students using Navi Surface in pairs to explore their achievements through a collaborative badge visualisation

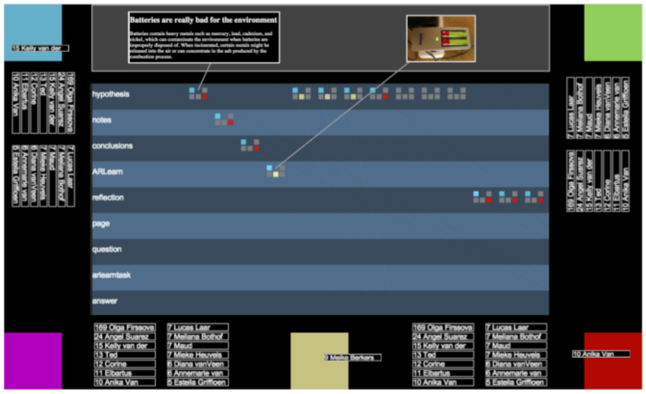

Figure 7 LARAe.TT Activities are shown in the centre of the screen. The top dropzone lets users expand an activity to get more details. Each user has a coloured, personal drop zone for highlighting activities

student's paths in the centre. The application provides a series of dropzones that allow students and teachers to physically drag particular activities to see more details of it in the form of text or pictures that are evidence of student activity for a particular IBL phase. Additionally, dragging a student name into a personal drop zone (coloured squares the figure) allows students to explore and filter their data according to the position of participants at the tabletop.

LARAe.TT was presented and evaluated with 15 participants (teachers, students and researchers) at a workshop. The evaluation explored how the tabletop application can assist both students and teachers during the IBL process. It was clear that it could facilitate students to assess their own progress and manage the distribution of work. LARAe.TT would not only help students explore personal achievements, but would also let them compare, reflect on and learn from the activities of their peers. Teachers on the other hand could invite students to the tabletop to initiate a discussion, to intervene, discuss progress, ask for clarification and reasoning, assess activities and point out peer activities for comparison. Overall, Navi Surface and LARAe.TT illustrate a very particular orchestration use for interactive surfaces to support reflection and post hoc assessment. The physicality of the tabletop and the design of the interface provide a unique opportunity to support collective f2f exploration of student's data with the purpose of facilitating discussion between students and their teacher.

4.4 Multi-Modal Learning Analytics for Researchers

The previous case studies suggest that interactive surfaces provide rich opportunities to support students' f2f interactions and teachers' orchestration. At the same time, they also provide researchers with a wealth of information to better understand the nature of social learning in the inter and post-active phases: researchers can use many data collection tools to capture students' interactions as they are learning new concepts by using cameras, microphones, motion sensors, mobile eye-trackers, galvanic skin response sensors, and emotion detection tools. We see interactive surfaces as environments where rich learning episodes can occur, which makes them ideal candidates for using multi-modal sensors. We illustrate this idea with the two examples below.

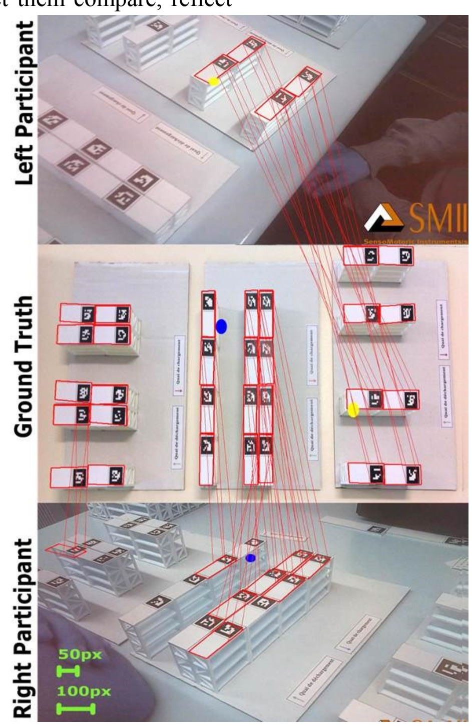

Figure 6. Two students analysing a static version of a Tangible interface. Red lines show the points used for remapping students' gazes onto a ground truth (middle figure)

4.4.1 Mobile eye-trackers and Joint Visual Attention

This case study is about capturing a fundamental building block of students' interaction: Joint Visual Attention (JVA). JVA is known by developmental psychologist and learning scientists to be a pre-requisite for any kind of high-quality collaboration, because it allows a group to build a common ground to effectively solve a problem. The second author and his colleagues [23] have developed innovative ways to capture JVA around interactive surfaces. Their methodology involves using fiducial markers (Figure 6) to remap students' gaze onto a ground truth. Since the fiducial markers are part of the tangible interface, the interactive surface becomes an essential part of being able to collect and meaningfully analyse the eye-tracking data. Having both gazes on the same physical plane allowed the researchers to determine whether students were jointly looking at the same location at the same time. They found that the number of times that JVA is achieved is not only correlated with students' quality of collaboration, but also reflects higher performances on the problem-solving task as well as higher learning gains. This kind of data stream allows researchers to generate reliable footprints of collaboration quality, and separate productive from less productive groups of students. This data could potentially be collected in real-time to help teachers decide which groups need attention and which ones do not need help.

One interesting aspect of multi-modal sensors is that they do not just allow researchers to more easily collect quantitative data, but also facilitate qualitative analyses. The next step of this line of research is to look at videos augmented with gaze information (Figure 6 is showing one frame of this kind of video) to support qualitative analysis of students' interactions. This kind of analyses was previously difficult to conduct, because it required researchers to position multiple cameras around a group to infer whether two students were simultaneously looking at the same location. Sensors can now provide this information to researchers, which can help speeding up the pace of qualitative work.

4.4.2 Motion sensors and students' physical mobility

This last case study is about capturing another key aspect of f2f interactions: students' ability to use their physical body to express ideas and manage collaborative processes. These movements can be manually coded or captured using a motion sensor. For example, Schneider & Blikstein [22] used a Kinect sensor to collect data from a study conducted with 38 students interacting with a tangible interface, resulting in 1 million data points describing their body postures. They then fed this matrix into a simple clustering algorithm to obtain the following prototypical body positions (Figure 8). Not surprisingly, they found that the time spent by students in the "active" posture (left graph of Figure 8) was positively associated with their learning gains while the "passive" posture (right graph) was negatively correlated with them. More interestingly, they found that the number of times students *transitioned* from one posture to another was the strongest predictor for learning. This suggests that the most successful students were the ones who not only acted, but also systematically stepped back to reflect on their actions and think about their next steps. With traditional qualitative approaches, it would have taken months to identify and code this kind of behaviour. Using sensors and unsupervised machine-learning, it took an order of magnitude less time to isolate this productive learning behaviour.

In conclusion, results suggest that surface devices, augmented with multi-modal sensors, provide researchers with rich opportunities to collect massive datasets about students' learning experiences. Those datasets can be then mined using machine-learning algorithms, or used to augment videos and facilitate qualitative analyses of students' interactions.

4.5 Other cases

Other case studies that we analysed are the following. The first author and colleagues investigated the impact of showing the teacher visualisations about the enactment of the macro-script during a class session through a Script Awareness tool [14]. This is the only example we are aware of, that directly supported the orchestration aspects of *Adaptation* and *Flexibility* to enhance the *Management* of the workflow of a multi-surface classroom. Lenh's work [8] was very similar to the first case study described above. His system captured from each small group using multiple tangible tables in a classroom. Then, a public dashboard was displayed on an IWB for all students and their teacher to be aware of their progress on the task in comparison with other groups of students. Recent work by Wang et al. [28] proposed similar visualisations of the progress of the task for students working with and sharing tablets (instead of tabletops). Similar cases of learning analytics applied to interactive surfaces are slowly emerging to support BYOD (bring your own device) strategies. An example is Learning Catalytics [21] which provides some visual analytics to teachers about students' progress and their misconceptions while collaborating in the classroom using tablets or mobiles.

5. DISCUSSION

This section presents a synthesis of conclusions that identify the degree of maturity, challenges and pedagogical opportunities of learning analytics and interactive surfaces. In the next subsections, we discuss different aspects of the case studies presented above, the implications of defining this design space, the particular affordances of surface devices and the kinds of analytics that are promising to support f2f collaborative learning challenges.

Table 2 Maturity of learning analytics applications utilising interactive surfaces. E=educators, S=Students, R=Researchers and ^{n}= number of studies

Orchestration aspects	Pedagogical phases: Pre-active	Pedagogical phases: Inter-active	Pedagogical phases: Post-active
Adaptation, Flexibility, & Intervention		E	
Regulation & Management		E^2,S^2	E^2,S^2
Awareness & Assessment	E	R^2, E^4,S^3	E,S
Design & Planning	E^2,R		E

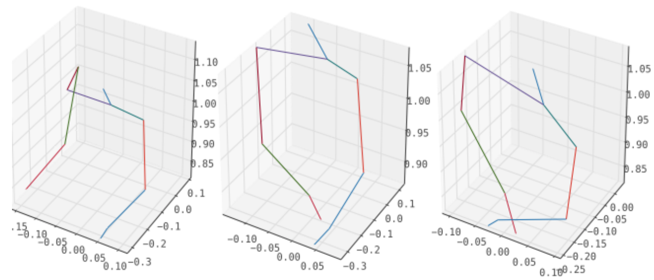

Figure 8. The results of the clustering algorithm on students' body posture. The left centroid is active, with both hands on the table; the middle one is semi-active, with one hand on the table; the right one is passive, with both arms crossed

5.1 Towards real time analytics in the field

A basic affordance of large surfaces is that (used well) they more readily support the ergonomic (perceptual, physical, cognitive, social) characteristics of groups than a small surface. So, it is not surprising that groupwork is a common denominator in most of the cases reviewed, but with the difference that they in some cases support novel kinds of interactivity, and critically, make them *traceable*. The case studies showed varied ways to capture students' interactions, enabling teachers to provide enhanced feedback while orchestrating a classroom, and permitting the collaborative exploration of student data. The combination of these technologies has the potential to open up new lines of research by allowing automatic processing and mining from large amounts of heterogeneous traces of f2f data (such as physical actions, gaze, body mobility, speech, etc). Critically, these technologies are not only analytics tools for researchers, but show promise for providing real-time feedback of activity to students and educators. The people who constitute the learning system are provided with data about their own process, whereas before, they were the object of study by researchers, who were the only people with the tools to capture and render such data. Manually analysing this kind of f2f data through more classical video coding and observational approaches is time-consuming. As surface analytics matures, real-time analytics could become practical in authentic classroom settings at runtime.

5.2 Learning analytics approaches

In the cases reviewed, interactive dashboards and visualisations were the most common ways to show educational data to educators and students. The focus was on providing information about the task [3; 4; 8; 15; 28] and class [14] progress (Case 1), students' interaction with the shared device (Case 2) [15; 17; 22], the class design [16; 17], and, to a lesser extent, the quality of the students' solution (Case 3) [17]. Only two studies provided notifications [15; 21] to the teacher during the inter-active phase to aid the decision making of the teacher in the classroom. Finally, detailed and more complex analytics that give information about more abstract aspects of learning such as achievement [4] and collaboration [23] have mostly been lab studies (Case 4).

5.3 Current applications and learning tasks

5.3.1 Suitable learning tasks

The most suitable tasks for surface technology seem to be those that involve a combination of talk, discussion, manipulation of digital or physical objects in a spatiotemporal representation plane, and/or that require larger sized displays. The tasks in the case studies included collaborative concept mapping [15; 17], brainstorming [15], team meetings [15], data exploration [3; 4], logistics training [8; 23], and a physiology challenge [22].

5.3.2 *Classroom dashboards*

The use of dashboards and visualisations in the classroom is still in its infancy. With the increasing use of digital surfaces in the classroom (e.g. tablets), it will be very common in the near future to see more implementations of systems that visualise key aspects of student's activity and/or performance or simply visualise or notify them for cases where students are disengaged, underperforming or not collaborating with their peers. This information could also be helpful for the students themselves to self-regulate their interaction and learning activities.

5.3.3 *Analytics for collaborative design*

The use of learning analytics to support learning design is also an underexplored area of application. The data captured by interactive surfaces and the orchestration technology can be valuable to facilitate teacher's reflection on their design [16; 17], even if the time constraints of the class make it challenging to make big changes on the original plan, they can re-design for the following sessions. One case study [17] illustrated how orchestration support can be provided by learning analytics at a macro level of iteration (across sessions), showing analytics about the planned curriculum compared to how it actually occurred.

5.3.4 *Sensors and multi-modal analytics*

Regarding more complex, multi-modal analytics approaches, the challenge is to feed these data back to students (and teachers) to help them make better informed decision and to support students' collaboration. Gaze awareness tools where students in a remote collaboration can see the gaze of their partner in real time on the screen can be highly beneficial to students. This allows them to monitor the visual activity of their partner, and anticipate their contributions, which leads to higher quality of collaboration and higher learning gains [23].

5.3.5 *Interfaces for teachers and students*

Visualisations of individual learner traces on shared surface devices can help in bootstrapping dialogue between teacher and students. On the one hand, they allow learners to gain insight into the learning activities of themselves and their peers and the effects these have, while allowing teachers to stay aware of the subtle interactions in their course. In addition, teachers and students can jointly agree on appropriate learning strategies to follow, based on collaborative discussion around real factual data [3].

5.4 Maturity and under-attended aspects

Table 2 presents an overview of the orchestration aspects, actors and pedagogical phases currently addressed by the analysed case studies. Most effort has been placed on supporting the orchestration aspects of *Awareness and Assessment* and in the inter-active and post-active phases of the learning activities (rows 2 and 3). By contrast, other cells are empty or are populated just by 1-2 exemplars. The orchestration aspect that refers to *Adaptation, Flexibility, & Intervention* has barely been explored. There is potential to develop solutions that can, for example, perform automatic or semi-automatic interventions in students' activities. There are still under-attended actors as well. For example, providing LA tools to enhance students' awareness or other orchestration aspects in the physical classroom has not been deeply explored. Table 1 (columns 9 and 10) also shows that there is potential to provide iterative support at a macro level. This can include providing continued LA support across sessions - bridging the physical world where interactive surfaces can capture some traces of f2f activity, with the digital remote access to resources. An alternative indicator of the maturity of this area of application is to observe to what extent the LA solutions can be readily deployed in authentic classrooms. Most of the examples analysed describe lab-based scenarios, indicating that this area is rapidly growing but is still exploratory. The only examples of LA classroom tools mostly supported the orchestration aspect of Awareness through teacher's [15] or public [8] dashboards.

6. CONCLUSION

This paper presented a description of the orchestration aspects, challenges and pedagogical opportunities of applying learning analytics solutions utilising interactive surfaces to facilitate a range of f2f tasks. As illustrated in Tables 1 and 2, this area of is still immature as the technology is co-evolving along with pedagogical practices that are beginning to recognise the value that these pervasive devices may offer. Our analysis framework helped us characterise the design space in terms of orchestration aspects that need to be addressed, along with the pedagogical phases that teachers or students need to accomplish in order to prepare for classroom sessions. This framework is promising to help decompose other LA deployments, especially for those scenarios that can be complex, involving iterative support across different classroom sessions and considering different tools, and multiple sessions, LA target users and orchestration aspects.

The paper points at future work still needed to support students directly, exploit further unexplored affordances of interactive surfaces (such as sketching), and also support other orchestration aspects, such as adaptation, flexibility, intervention, management, design and planning. Besides, most LA support through interactive surfaces has focused on providing visualisations and dashboards. Other analytics techniques look particularly promising for surface tools, given the activity data they are good at capturing. These may include multi-modal analytics (e.g. traces of physical actions, or learning analytics approaches for tasks that require handwriting and sketching using interactive surface), analytics from heterogeneous sources of data (e.g. coming from different devices or education software), and the provision of (semi) automated systems' interventions, alarms, or feedback.

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